NASA ENERGY AND WATER CYCLE STUDY NEWS

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Closing the Water Cycle
Using a Constellation of Satellites

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Remote Sensing Systems, Santa Rosa, CA, USA

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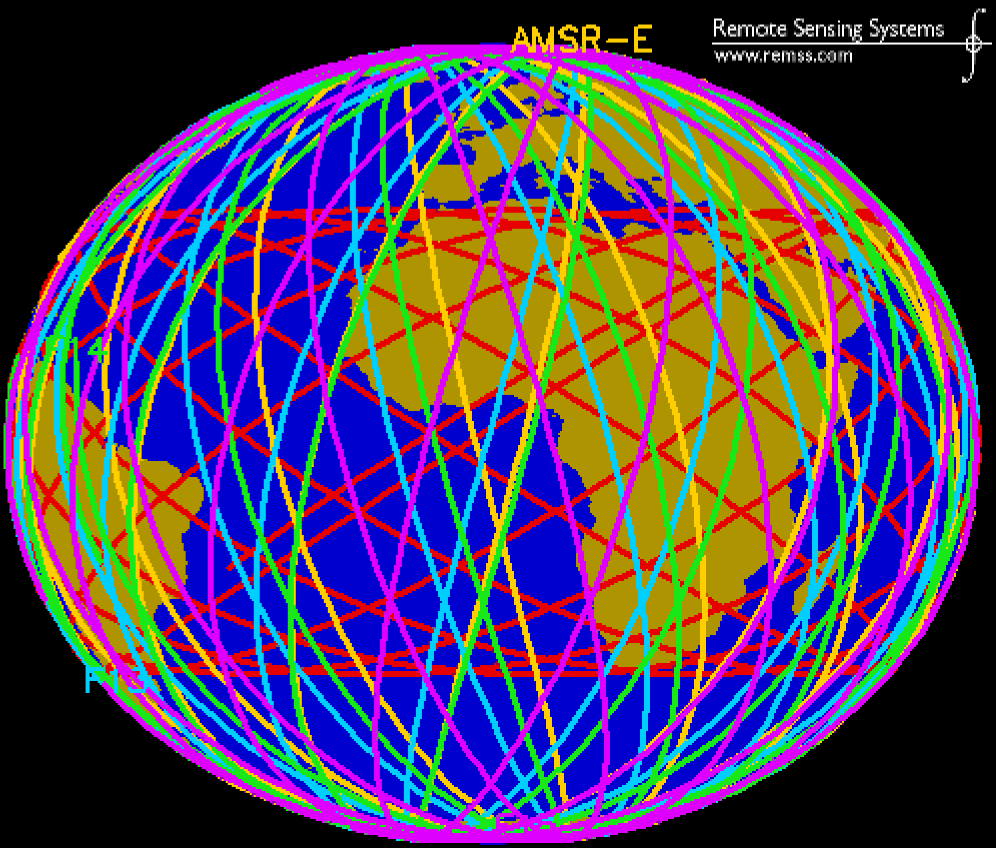
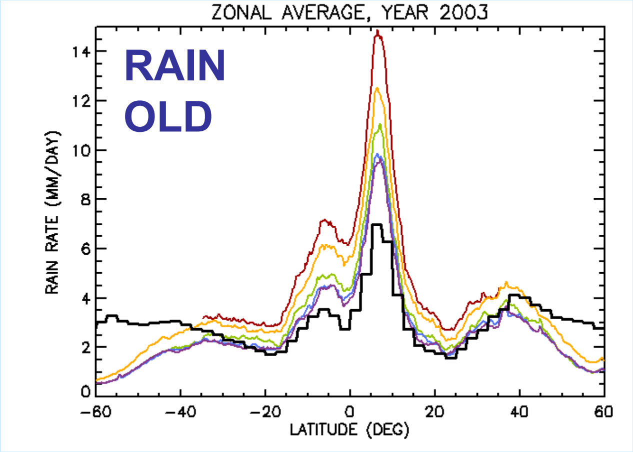
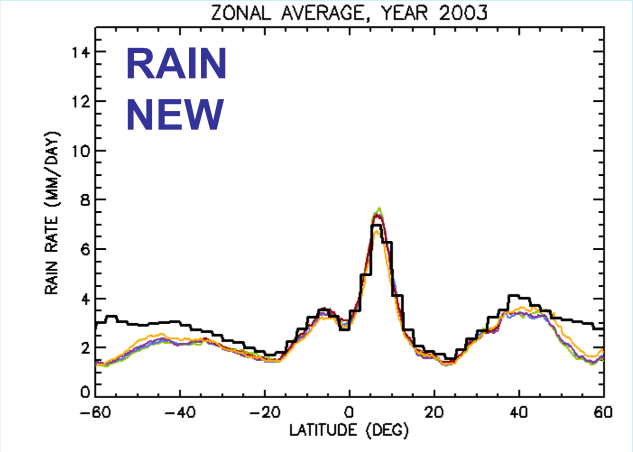
Earth Observation with a Constellation of Radiometers

SSM/I: F13, F14, F15 ; TMI ; AMSR-E



Rain Rate Intercalibration Completed

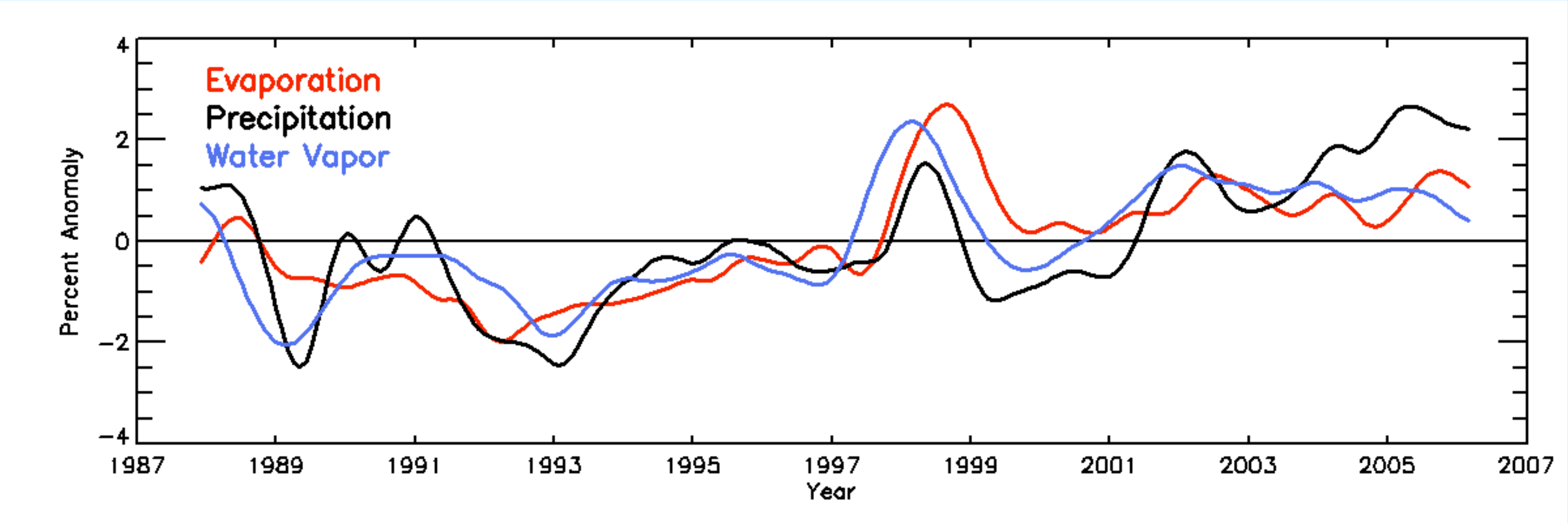




F13 (green), F14 (blue), F15 (purple), AMSR-E (orange), TMI (red), Global Precipitation Climatology Project (black)

- Our new rain algorithm: **UMORA** (**U**nified **M**icrowave **O**cean **R**etrieval **A**lgorithm) is a modification of the Wentz and Spencer (1998) approach
  - Improved beamfilling: modeling saturation and resolution dependence (removed biases among different sensors)
  - Improved rain column height: constrained to data (removed tropical biases)
  - Improved calibration: 0.05K
- Hilburn and Wentz, 2008: Intercalibrated passive microwave rain products from the Unified Microwave Ocean Retrieval Algorithm (UMORA), *J. Appl. Meteor. Climatol.*, **47**, 778-794. (March 2008 Issue)

Indirect Validation using Hydrological Consistency

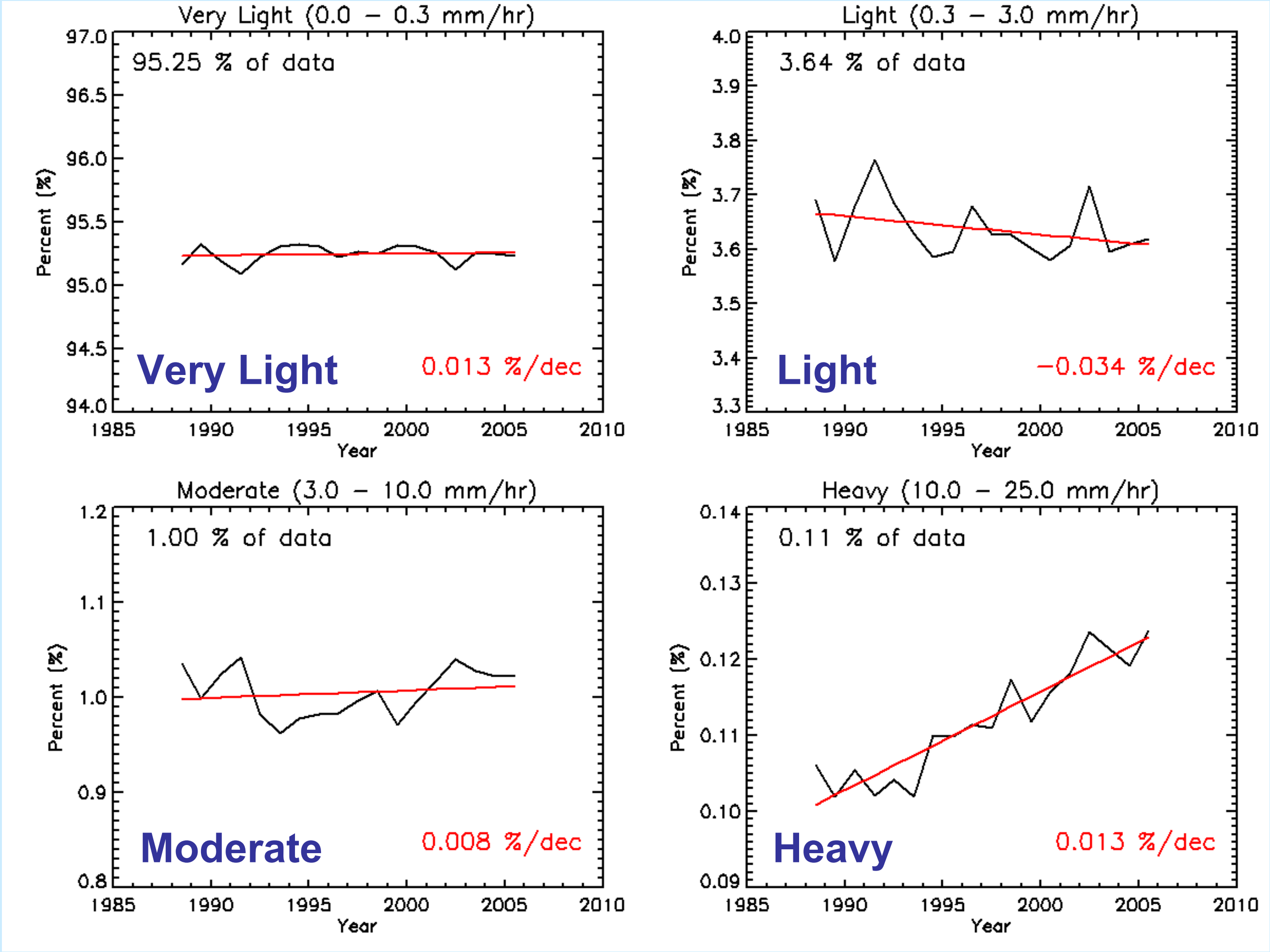


- Global evaporation balances global precipitation (with a static, latitude-dependent adjustment to rain)
- Average evaporation: 962 mm/year
- Average precipitation: 951 mm/year
- Imbalance on the order of 1%

- Trends in evaporation and precipitation have the same magnitude as trends in water vapor, in contrast with climate models
- **Evaporation trend: + 1.3 % / decade**
- **Precipitation trend: + 1.5 % / decade**
- **Water Vapor trend: + 1.4 % / decade**

Climate prediction models predict a muted response by precipitation see Wentz et al., 2007, *Science*.

Increase in Heavy Rain



consistent with Trenberth

These are for global oceans, tropical oceans the same

The Hierarchical Context

- Evaporation (**E**)
- Precipitation (**P**)
- Water Vapor (**V**)

The *Science* paper
(one-dimension: time)

Wentz et al., "How much more rain will global warming bring?", *Science*, 13 July 2007.

- Averaging over time (~month) at a <u>particular location</u> we have:

div Q = E – P

The next step:
add 2-D space

- Water Vapor Transport (**Q**) (a vector)
- Water Vapor Transport Divergence (**div Q**)

First Approach: Feature Tracking

- Water Vapor Transport
  - Initial idea: using feature tracking to deduce the transport velocity
  - Problems with non-conservation of water vapor and the optical flow aperture problem, also issues near coastlines
  - Tested using on-orbit simulation with NCEP wind and humidity
  - Monthly average transports are ok... but the divergence field lacks proper structure

Current Approach: Using Radiometer Derived Wind Vectors

- In the process of testing feature tracking, found that the surface wind vector was highly correlated with the water vapor transport vector (as would be expected)

- Ardizzone/Atlas Winds (Level 2.5)
  - Based on our radiometer wind speeds, but assigned a direction
  - A very high quality climate data record
  - Enthusiastically recommend its use!

DISCOVER
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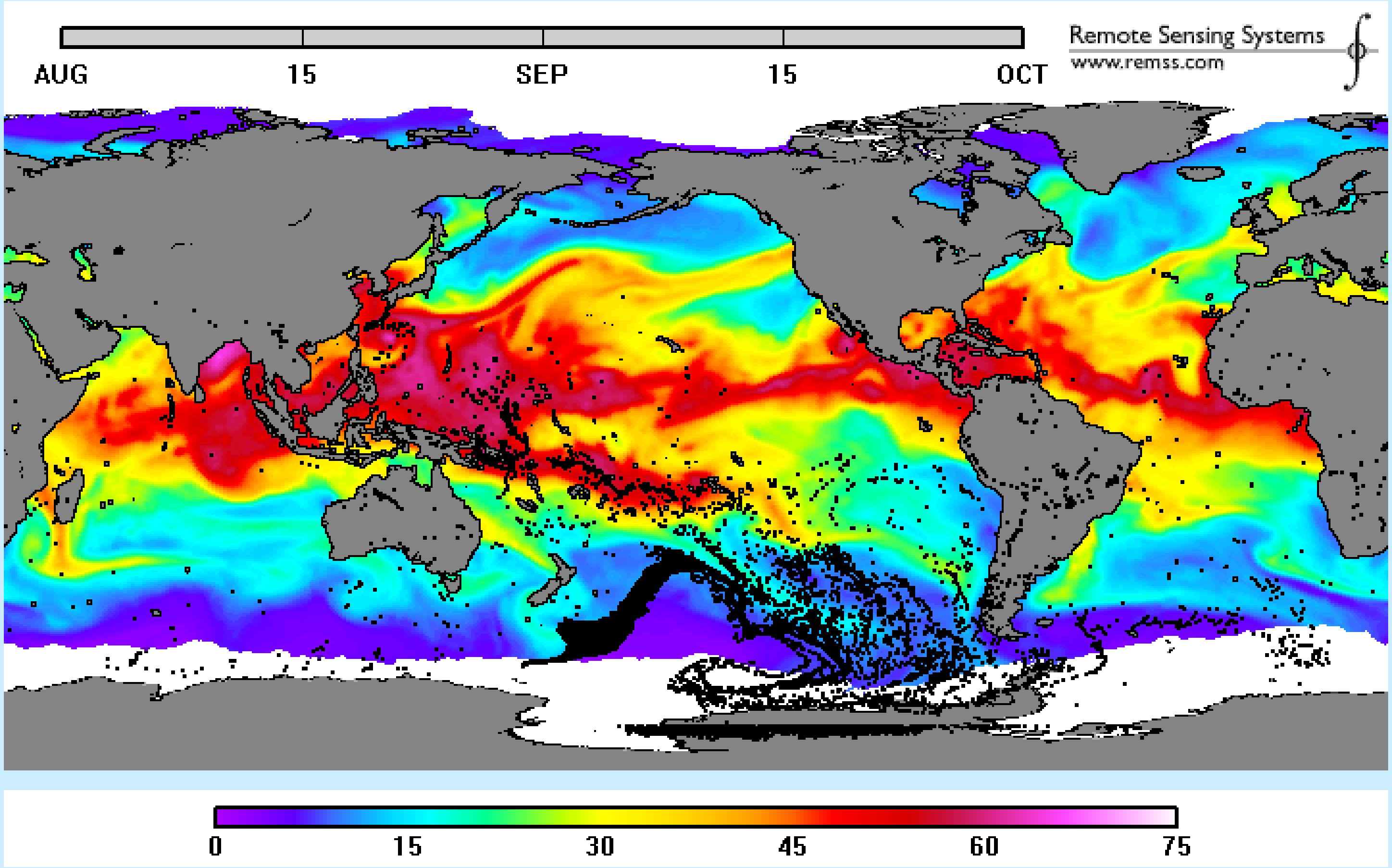
Trajectory Analysis with Atlas Winds

Note that particle positions (determined by Atlas winds) line-up with water vapor



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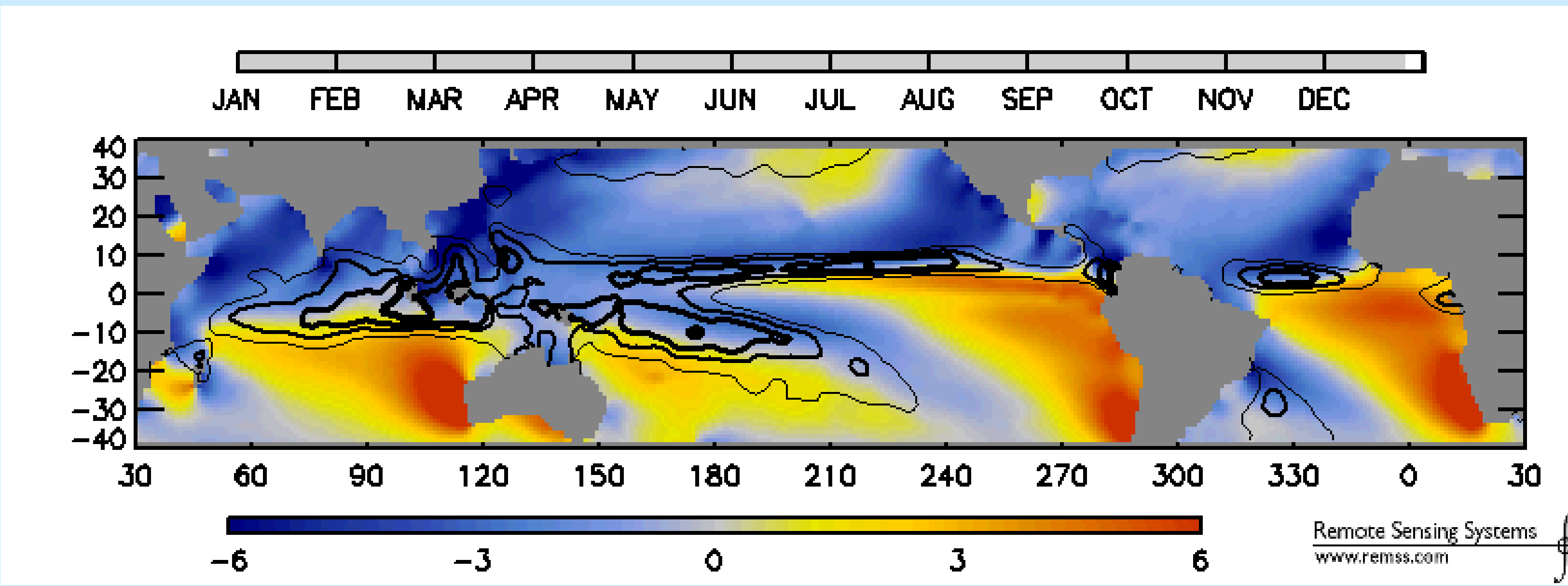
Color: **water vapor (mm)**
Aug-Sep 2005

Seasonal Cycle of V-Wind and Rain

using TMI UMORA rain rates and Atlas Level-2.5 TMI winds

Rain occurs where there is convergence



<u>Color:</u> Meridional Wind (m/s)

<u>Contours:</u> Rain Rate (4, 6, 8, 10 mm/hr)

going from thin to thick

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TMI: 1998-2005

What goes into PMWC Product?

- Precipitation (Rainfall + Frozen Precip)
  - SSM/I, TMI, and AMSR-E rain rate retrievals +
  - Diurnal and other intersatellite adjustments (UMORA paper) ^
  - Rain to precip adjustment (lat/mon climo; based on GPCP) ^
- Evaporation
  - Reynolds SST (X,C-band only available since 1998,2002)
    - Note: need C-band for global (warm+cold) SSTs
  - SSM/I, TMI, and AMSR-E wind speed retrievals +
  - Buoy-based wind speed adjustment (Science paper) ^
  - RH, TA-TS climatologies (Science paper)
- ((Water Vapor) Transport) Divergence
  - SSM/I, TMI, and AMSR-E water vapor retrievals +
  - SSM/I, TMI, and AMSR-E wind vectors (Atlas L2.5) ^
  - SFC to WVT adjustment (climatology, based on NCEP)

+ RSS Product
^ Based on RSS Product

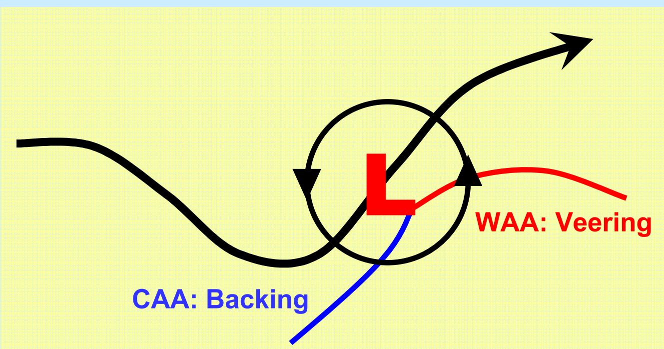
SFC to WVT Adjustment

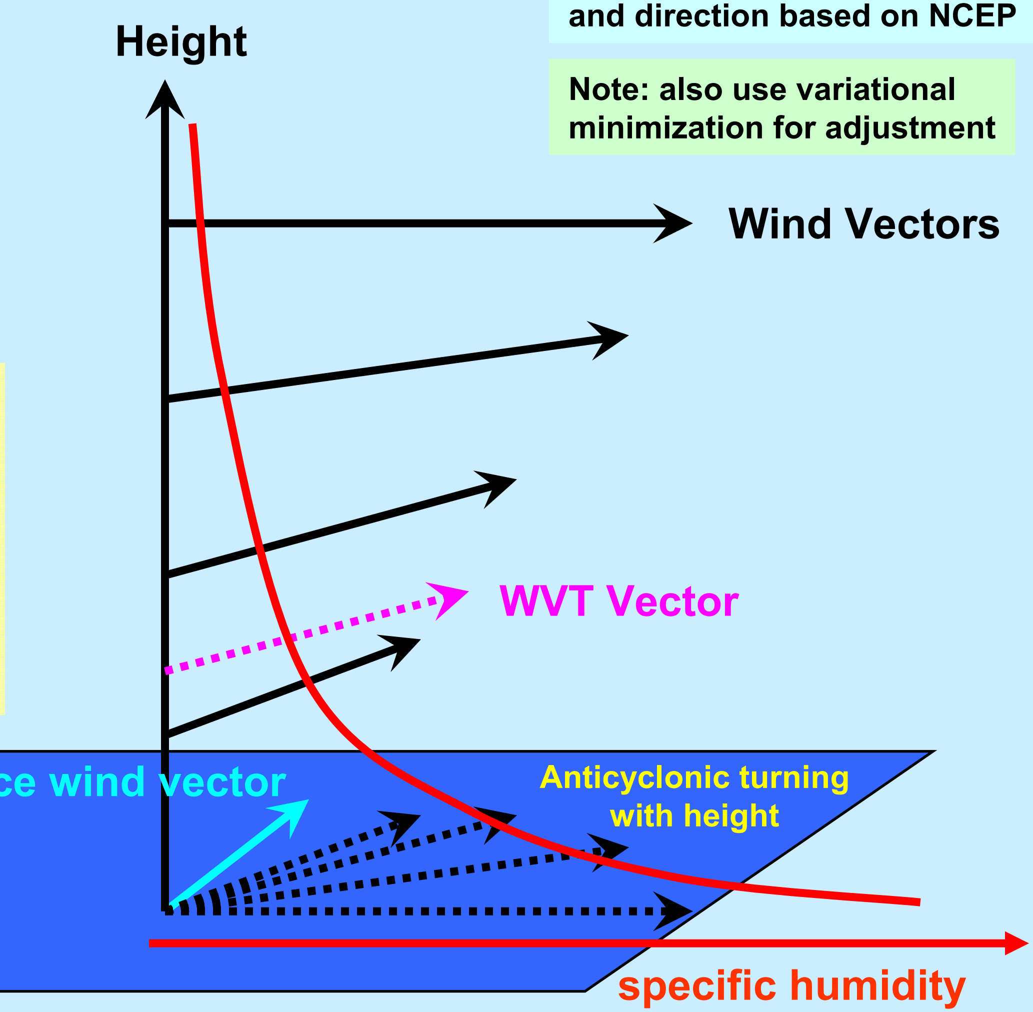
$$\vec{T} = \frac{\vec{\mathbf{Q}}_{WVT}}{V} = \frac{\int_0^{p_s} \vec{\mathbf{W}} q \frac{dp}{g}}{V}$$

$$V = \int_0^{p_s} q \frac{dp}{g}$$

Using simple latitude-dependent climatological adjustment for speed and direction based on NCEP

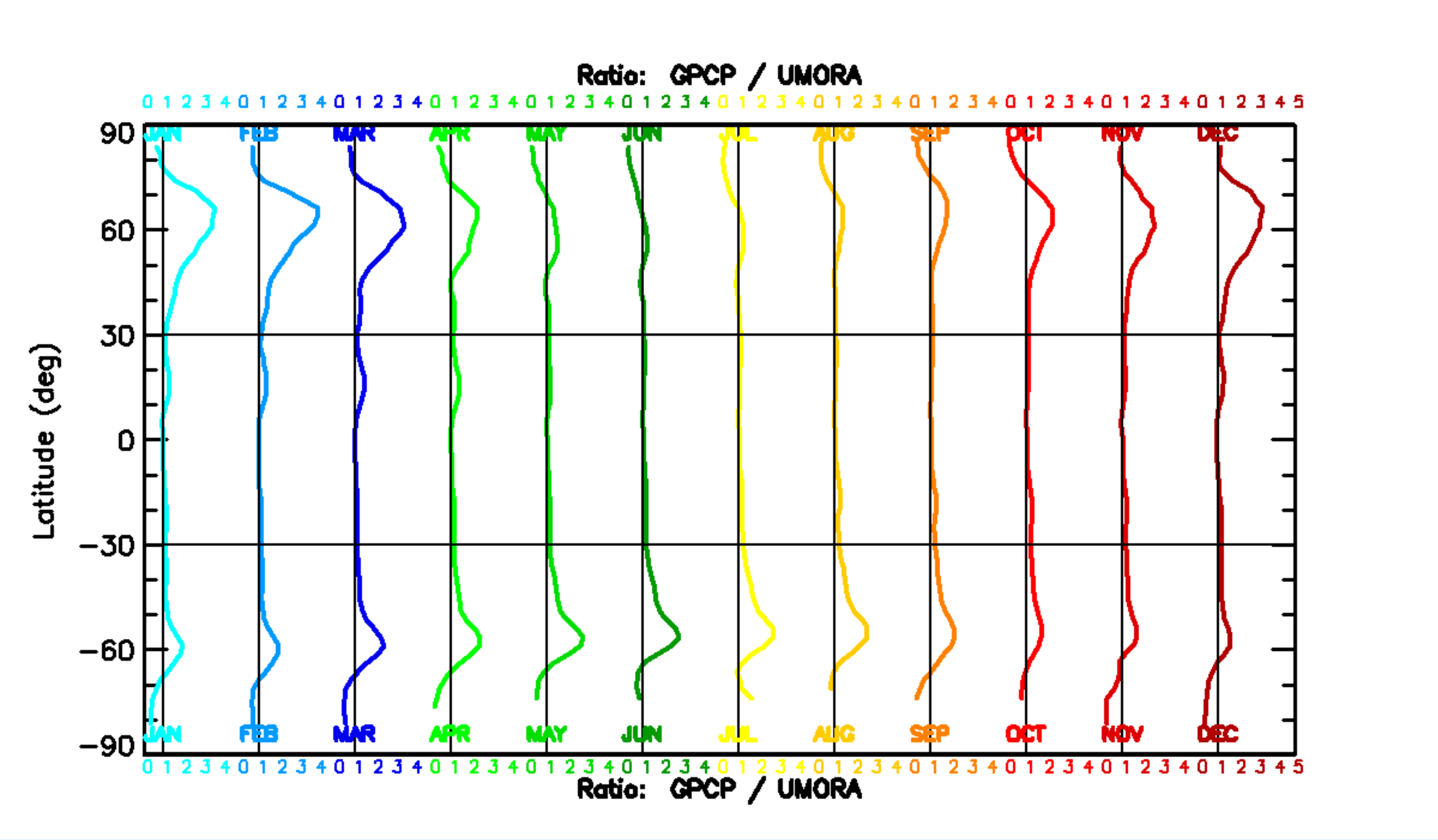
Note: also use variational minimization for adjustment





High Latitude GPCP-UMORA Differences Are Seasonal

GPCP / UMORA rain rate ratio for 1988-2005

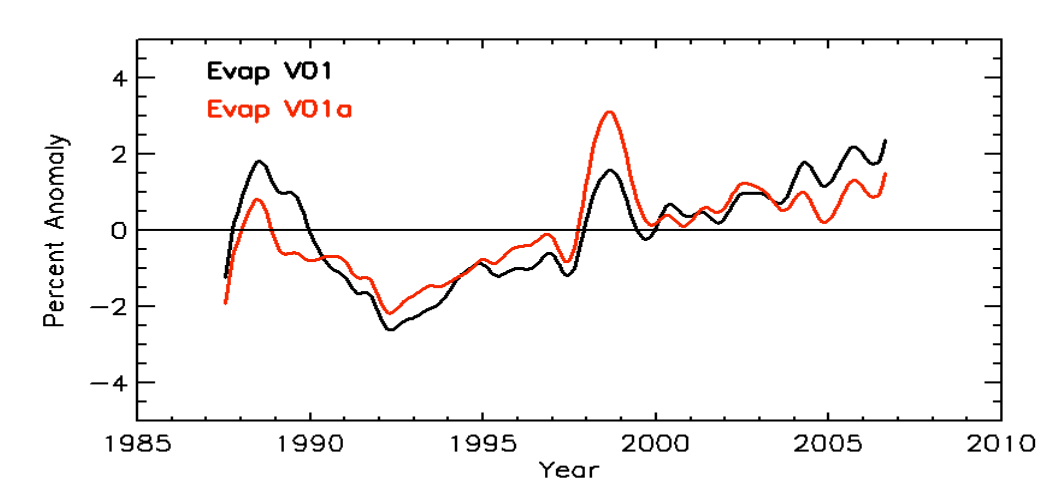


**Note that UMORA is much lower than GPCP in the winter hemisphere.
The patterns are similar to Petty (1995) snow observations.**

PMWC vs Liu Products

- **PMWC (Passive Microwave Water Cycle) Product**
  - Ocean only, whole globe
  - 0.25 deg, Monthly resolution
  - Available from July 1987 – December 2006
  - WVT-U, WVT-V, WVT-Div, Evap, Precip, Vapor
- **Liu Transport Product**
  - Ocean only, -30 to +30 N
  - 0.5 deg, Daily resolution
  - Available from July 1999 – December 2005
  - WVT-U, WVT-V

New PMWC V01a Dataset

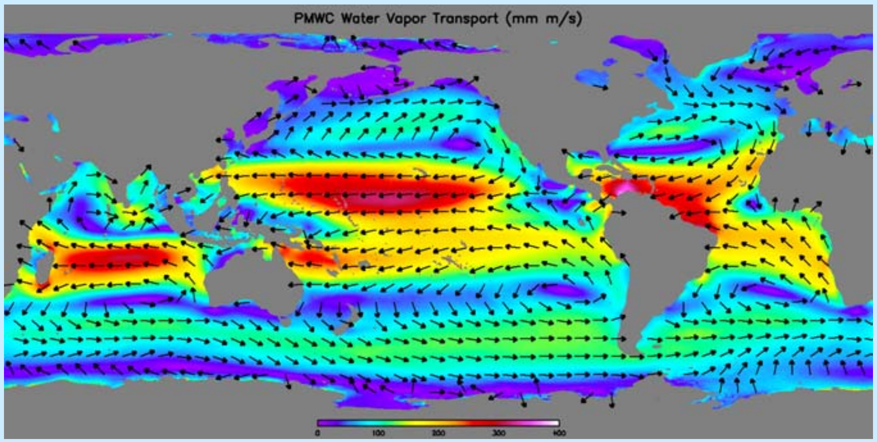


- Discussion on Google Groups
- Based on collaboration with Pete Robertson
- Wentz et al (2007) wind speed adjustment
  - Based on buoys
  - Magnitudes less than 0.1 m/s
- No net effect on trend

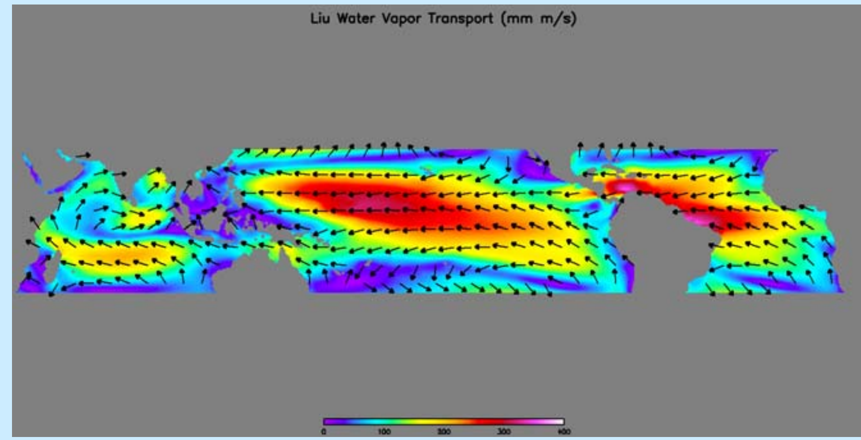
Water Vapor Transport

All comparisons 2000-2005

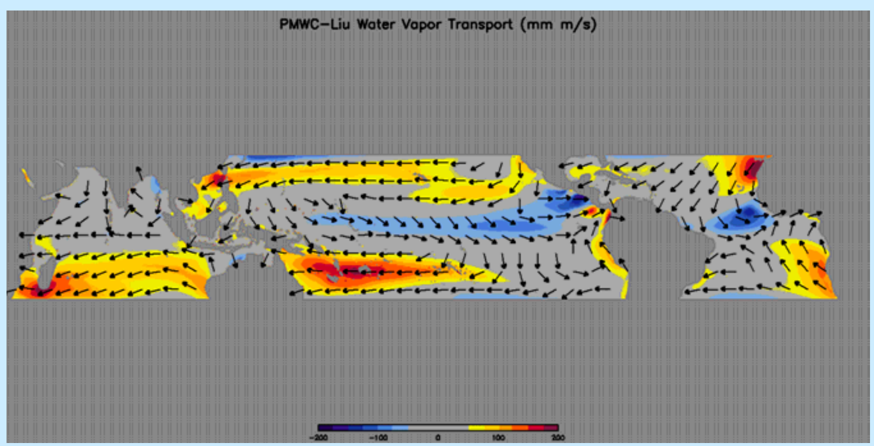
P M W C



L i u



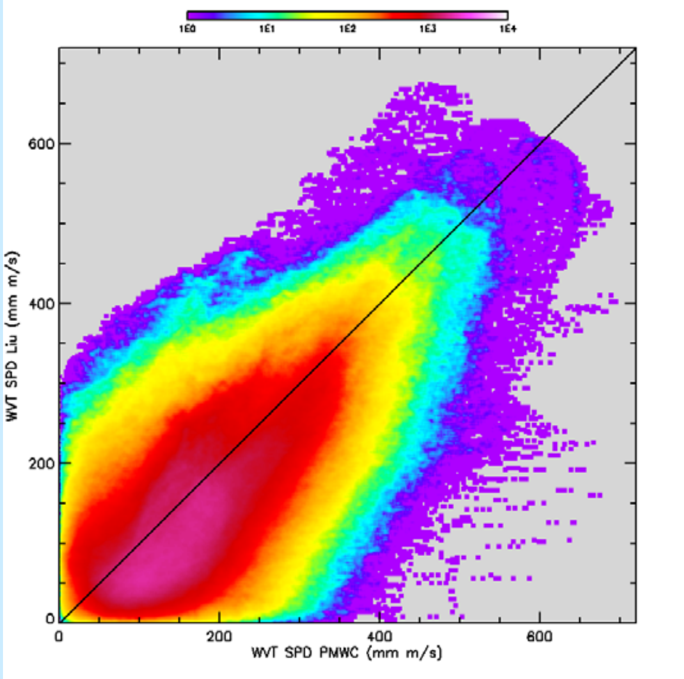
P M W C – L i u



Water Vapor Transport

WVT Speed

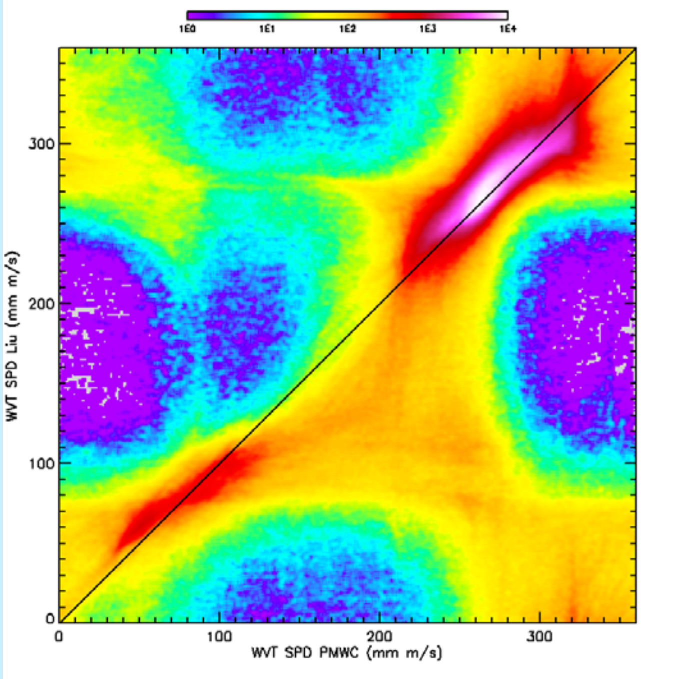
Liu



PMWC

WVT Direction

Liu



PMWC

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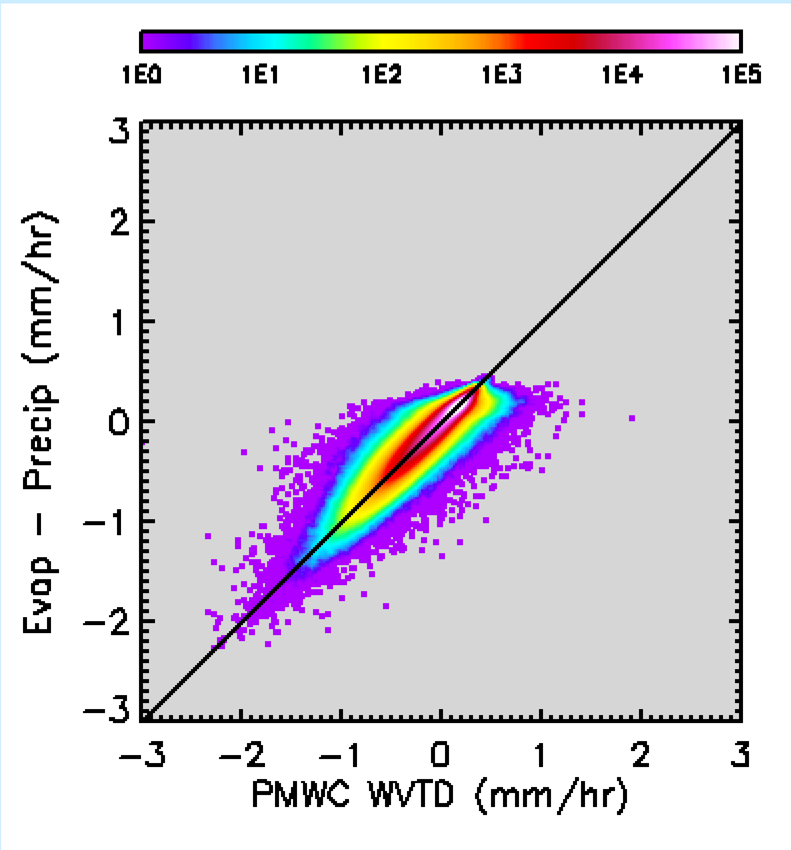
Water Vapor Transport Divergence

P M W C

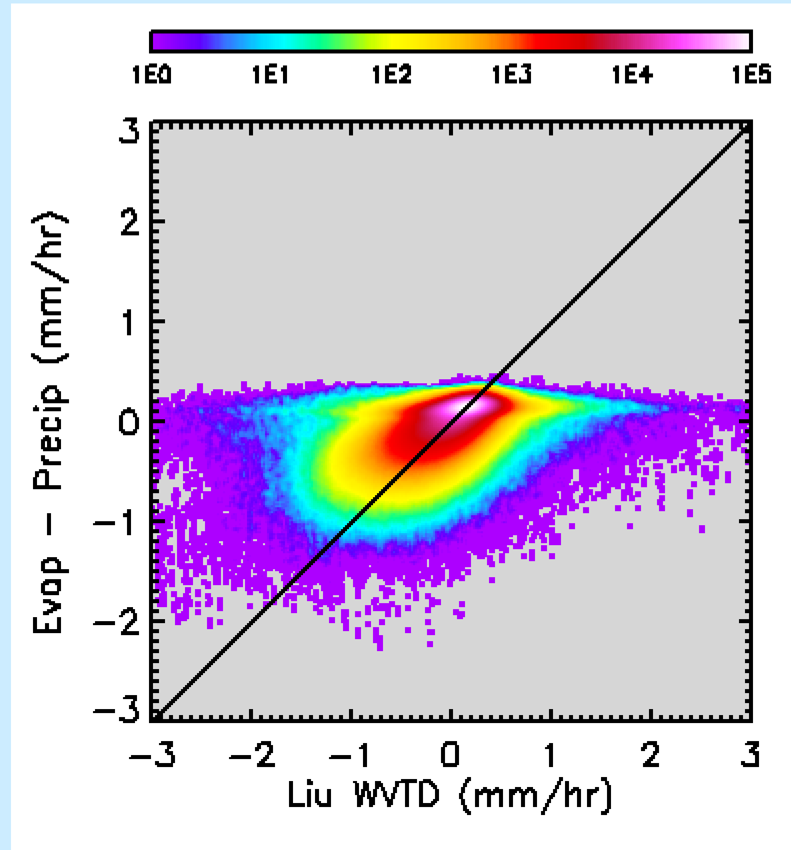
Evap - Precip



WVT Div

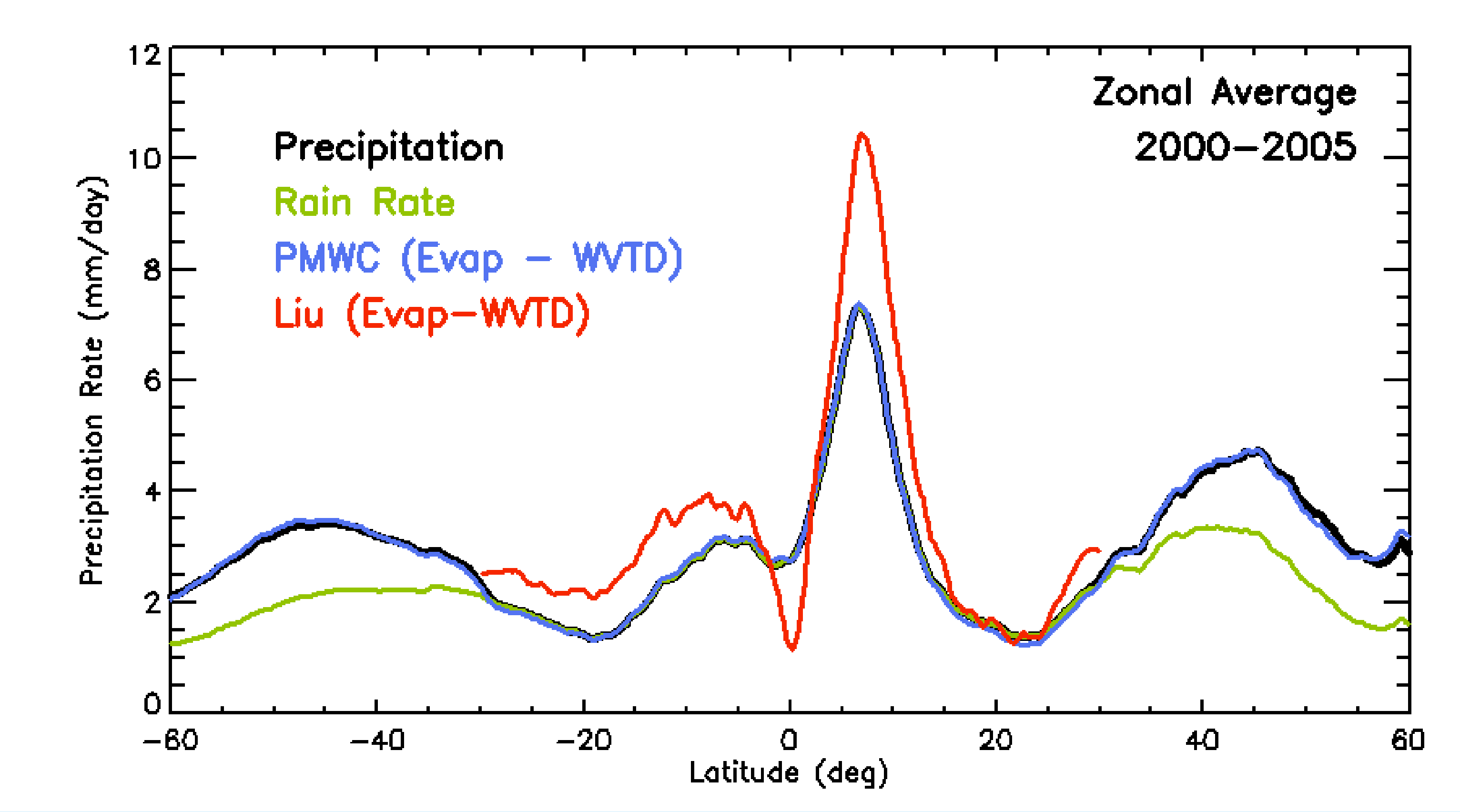
L i u

Evap - Precip



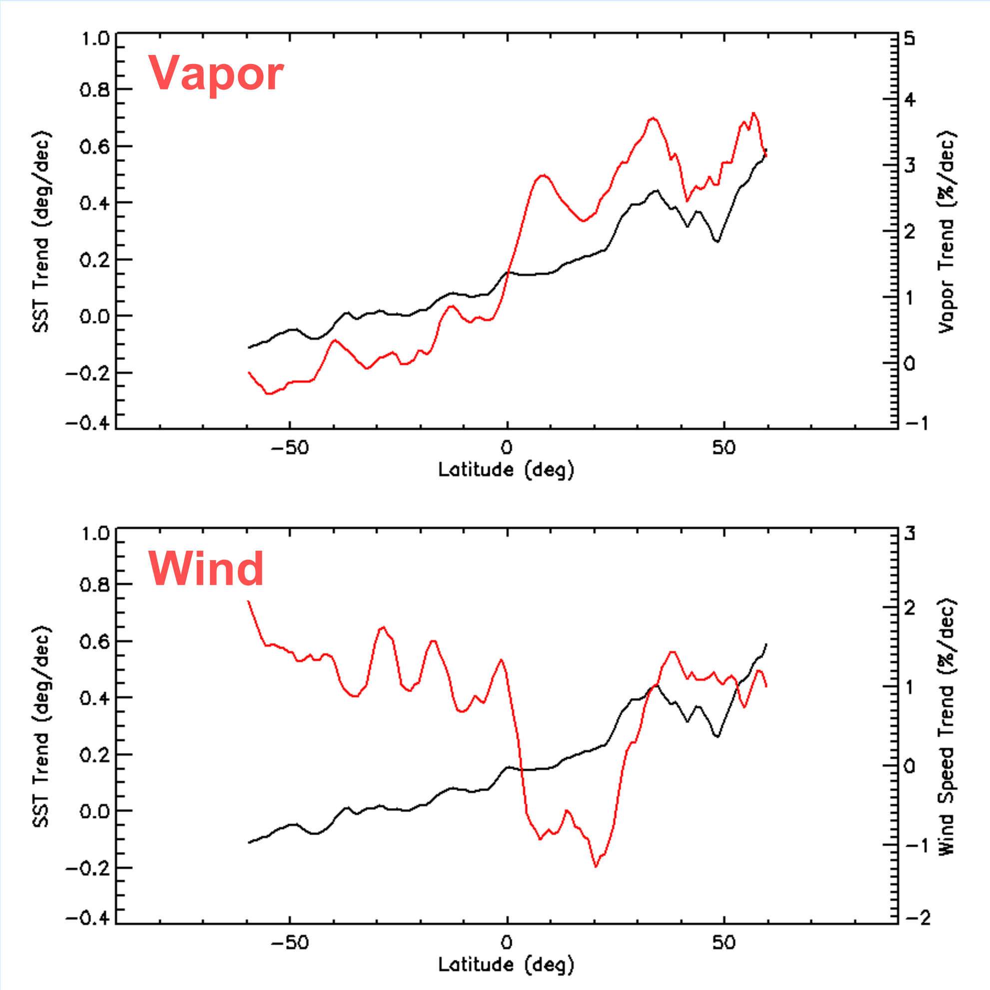
WVT Div

Precipitation Implied by Hydrological Balance



Vapor and Wind Trends

Black line: SST trend



d(*SST*) & d(*Vapor*)/(*Vapor*):
Correlation: R = 0.94

Vapor trend:
zonal average structure like SST

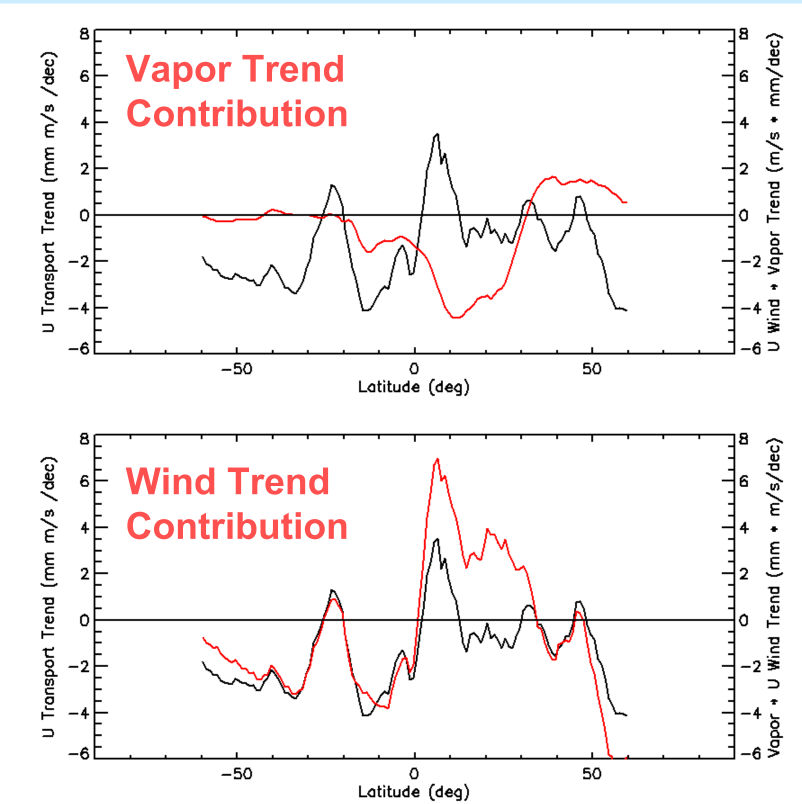
d(*SST*) & d(*Wind*)/(*Wind*):
Correlation: R = -0.28
(Wind Speed)

Wind trend:
latitude dependent structure
different than SST

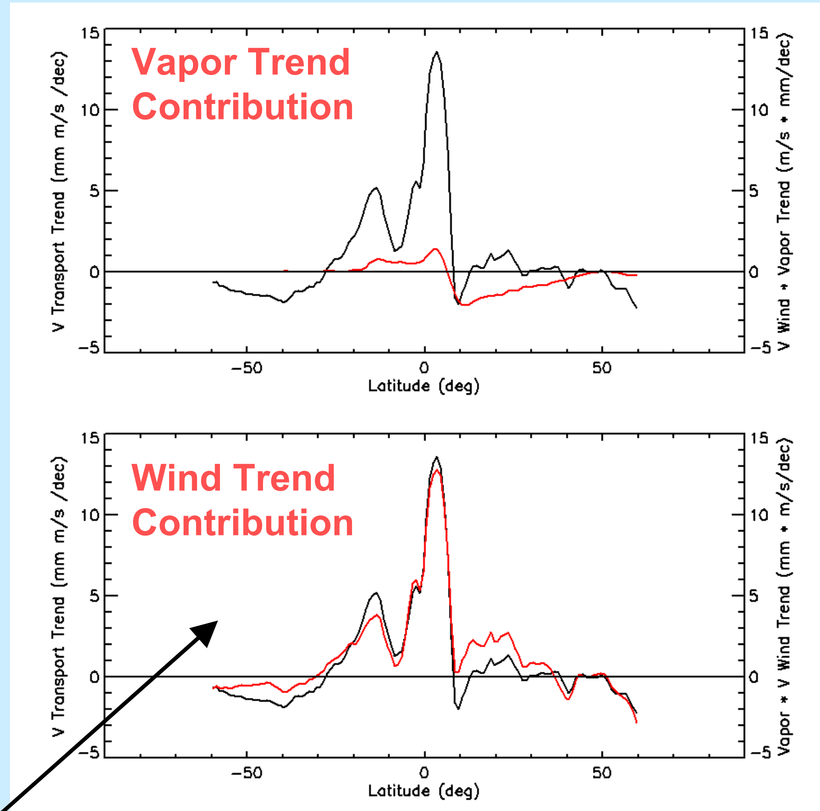
Transport Trends

Black line: transport trend

Zonal Vapor Transport



Meridional Vapor Transport



(Trend in meridional wind) * (Mean vapor) = (Trend in vapor transport)

Conclusions

- Intercalibration of rain rates completed
  - *JAMC* paper describes rain algorithm changes
  - Used in *Science* paper; found precipitation trends in balance with evaporation trends, but in conflict with climate models
- PMWC product available
  - Monitoring WVT with a constellation of satellites
  - Available from Kyle (hilburn@remss.com) and CREW FTP
  - PMWC and Liu transports are similar, but have some important differences
  - PMWC and Liu divergence values are different, PMWC product balances better
- Thoughts about the water cycle
  - Balancing E, P, and WVT Div is much like the vertical velocity estimation problem in meteorology
  - The 2-dim (i.e., regional) water cycle is apparently more sensitive than widely appreciated